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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Describes methods of measuring airblast overpressures above 170 dB (1 psi or 6.9 kPa), resulting from detonation of explosives or firing of guns. Describes the direct-pressure method and the shock wave velocity method for measuring airblast. Includes techniques for calibrating transducers used for measuring airblast overpressure, and describes overpressure-measuring devices.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

DRSTE-RP-702-103
*Test Operations Procedure 4-2-822 28 September 1981
AD No.

ELECTRONIC MEASUREMENT OF AIRBLAST OVERPRESSURE

1. SCOPE. The detonation of an explosive or the firing of a gun precipitates the sudden release of gases into the surrounding air, causing a shock wave or front to be propagated outward from the source. The shock front velocity is supersonic, a function of the overpressure behind the shock front. This TOP describes procedures for measuring high-level airblast overpressures of 171 dB (1 psi or 6.9 kPa) and above. These measurements are necessary to determine damage potential of airblasts, or to compare one weapon to another. Two measurement techniques are discussed: direct pressure and shock wave velocity. Devices used for measuring overpressure are described in Appendix A. NOTE: Procedures for measuring overpressures of 170 dB and below and steady-state noise are contained in TOP 1-2-608.[1]** (In the lower ranges, overpressure is often referred to as "sound pressure level".) The paper blastmeter method of measuring airblast overpressure is covered in TOP-4-2-823.[2]

*This TOP supersedes MTP 4-2-822 dated 22 July 1970.

**Footnote numbers correspond to reference numbers in Appendix G.

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As in many areas, improved airblast instrumentation and measuring techniques are constantly being developed. This TOP should not be perceived as precluding the use of new instrumentation or measuring techniques when they are proven to be superior.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

ITEM	REQUIREMENT
Testing site	Cleared area that is flat; free of gravel and rocks; without trees or structures that could cause reflection
Explosives or weapons	
Fragment guards	Earthen barricades or steel plates

2.2 Instrumentation.

ITEM	MAXIMUM PERMISSIBLE ERROR OF MEASUREMENT*
Velocity and blast gages (see Appendices A and D)	$\pm$5-10%, or as determined by purpose and cost of test
Electronic recording system (see Appendix C)	$\pm$ 1%
Radiosonde and meteorological instrumentation	$\pm$1% air pressure $\pm$1° C air temperature $\pm$1 meter/sec wind velocity

3. PREPARATIONS FOR TEST.

a. Calibrate each gage on a serial number basis according to Appendix D to ascertain its accuracy. NOTE: Preferably, use one of the verified laboratory calibration methods, but if there is a lack of suitable facilities, it may be necessary to calibrate by means of pentolite explosions. This is an elaborate method that involves detonating three pentolite explosions before and three after the test. (There is no inherent accuracy corresponding to gage type.)

b. Use best test practices, i.e., make sure transducers are isolated from the ground, shock-mounted, flash/thermally protected, and operated within the specified ambient temperature ranges. Protect cables from the blast (by placing them in conduit or by burying them), and run them from the transducers away from the direction of propagation of the blast wave. Long lines should be tested to ensure that they do not degrade rise time of records.

*Values may be assumed to represent $\pm$ 2 standard deviations; thus, the stated tolerances should not be exceeded in more than 1 measurement of 20.

c. Position recording instrumentation far enough away from the detonation so as to be minimally affected by the blast. However, make sure maximum cable length from the instrumentation recording point to most remote gage does not exceed 150 m. In some cases (for large explosive tests), very long lines are required. Line drivers are needed in these situations to maintain frequency response.

d. Protect recording instruments from blasts and fragments with a barricade of earth or steel plate if large charges are detonated.

e. Protect cabling between blast gages and recording instrumentation from blasts and fragments as required.

f. When making measurements to compare with standards for human tolerance to muzzle blasts (MIL-STD-1474B)[3], measurements of muzzle blasts should not be compromised by other test requirements.

NOTE: Give careful attention to test setup and data analysis to ensure that results are representative of the blast wave, rather than displaying anomalies due to extraneous effects. Each type of transducer has inherent advantages and disadvantages; no one type has proven best for all situations. Recording instrumentation that is available, the measurement situation, and the specific type of measurement required will determine the type of transducer and mounting arrangement.

4. TEST CONTROLS.

a. Make sure all personnel exposed to hazardous noise or blast levels wear hearing protection as required by AR 40-5, TB MED 501[4], and the applicable SOP. Personnel who will be occupationally exposed to peak pressure levels of impulse noise above 140 dB shall be entered in a hearing conservation program as described in TB MED 501. This TB also requires that protective devices (ear plugs or muffs) be worn when impulse noise levels exceed 140 dB, except during combat. Exposure to impulse noise greater than 165 dB requires the wearing of ear plugs AND ear muffs or a noise-attenuating helmet.

b. During tests, neither the operator nor crew members shall occupy the location(s) where the airblasts are being measured, unless these people are essential to the operation of the test item, and the hearing protection provided is capable of reducing the expected airblast to nonhazardous levels.

NOTE: Human tolerance to blast overpressure is being studied intensively by the Army. It is still not certain how much blast overpressure is acceptable for human exposure, and whether parts of the body other than those related to hearing are sensitive to blast. (For definition of A-duration, B-duration, and evaluation procedures related to acceptable human exposure to muzzle blasts, refer to MIL-STD-1474B[MI], TB MED 501, and ARBRL-SP-00014.)[5]

c. Ambient noise level for impulse noise tests shall be at least 25 dB below the peak noise being measured.

d. Do not conduct tests when wind velocities exceed 19.3 km/hr (12 mph) or during precipitation.

e. When feasible, noise measurements shall be made without reflecting surfaces, including personnel, other than those people essential to operation of the test item, within 30 m.

5. PERFORMANCE TESTS. Four types of pressure are associated with a shock wave in air: static (side-on [P_s]), reflected (face-on [P_r]), dynamic, and the sum of

side-on and dynamic, known as stagnation (^{P}stag). Figure 1 shows three of the types of blast pressure, examples of their relative values, and typical wave forms that could be expected in a shock tube. Figure 2 is a photograph of muzzle blast waves.

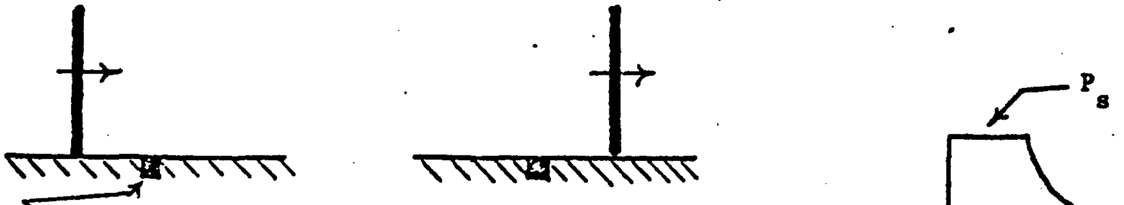
Side-on or static pressure is the pressure behind the free field blast wave. It must be measured by a transducer mounted perpendicular to the direction of wave propagation, and the transducer must not interfere with the propagation of the wave. Face-on or reflected pressure is that pressure developed when a blast wave strikes an infinitely large wall that is perpendicular to wave propagation and reflects back in the exact opposite direction. Dynamic pressure is caused by air flow behind the wave. Stagnation is the sum of static (side-on) pressure and dynamic pressure. Blast waves always travel through air at supersonic velocities. This wave propagation should not be confused with steady state supersonic air flow. The particle flow behind a blast wave is always slower than the wave propagation velocity. At blast pressure levels below ~350 kPa, the particle flow behind the wave is subsonic.

5.1 Muzzle Blast Test. Energy released by propellant combustion launches the projectile and creates muzzle blast, the principal source of noise when weapons are fired. The pressure field created by muzzle blast is symmetrical about the line of fire, but is not spherically symmetrical. The center of pressure moves along the line of fire, and steep gradients exist near the muzzle. Extreme care must therefore be used in placing transducers. In addition, since the center of pressure moves, there is no single point to which transducers can be aligned. For measurements near the muzzle, it is desirable to use transducers configured so that they are omni-directional in one plane. Unless directed otherwise, only side-on pressure will be measured in muzzle blast tests. The current standard for evaluating crew hazard (MIL-STD-1474B) is based on side-on pressure. If structural damage is of interest, it may be more appropriate to measure face-on pressure on the reflecting surface of interest. (NOTE: For recoilless rifles and rockets, the principal noise is emitted at the breech or tail rather than at the muzzle. The same procedures for blast measurement apply, except that the transducers are aligned about the rear of the system instead of the muzzle.)

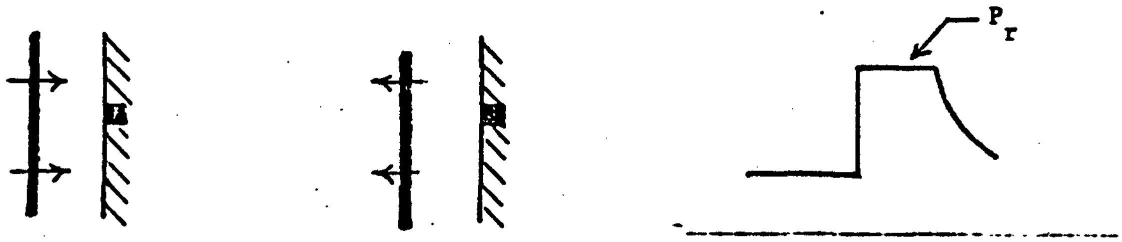
5.1.1 Method.

a. Place transducers radially around the weapon at crew positions (for measuring side-on overpressure versus time), with the muzzle placed at the transducer grid center (see Figure 3 for example). (For recoilless rifles, the grid center is at the rear of the breech, and for rockets, at the rear of the rocket motor.) For normal artillery weapons, the tube will be horizontal; for mortars, when the weapon is at minimum service elevation, the muzzle will be the reference point for the grid center. The 0° to 180° line will coincide with the axis of the barrel of the weapon in a plan (top) view, with the line-of-fire in the 0° direction. Special attention should be given to detail in positioning a transducer at each crew location. (NOTE: If a 140-dB contour line is required, follow instructions in 5.2.1.d of TOP 1-2-608.)

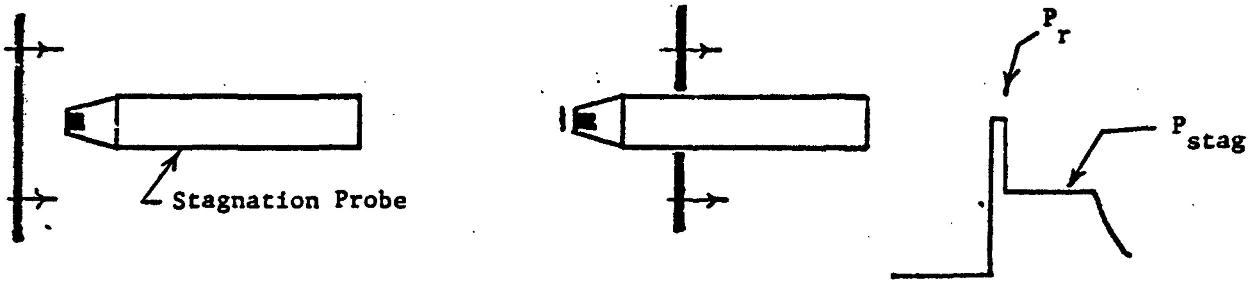
b. Mount all transducers (see Appendix B) at a height (to center of sensitive element) of 1.5 m for a standing crew member or 0.8 m above seat position for a crew member in a sitting position.



SIDE-ON PRESSURE



FACE-ON PRESSURE



$$P_{stag} = P_s + \frac{\rho U^2}{2}$$

P = air density
U = speed of shock front

STAGNATION PRESSURE

P_s (KPa)	P_r (KPa)	P_{stag} (KPa)	SHOCK VELOCITY (Meters/Sec)	PARTICLE VELOCITY (Meters/Sec)
10.0	20.8	10.4	355.0	23.1
30.0	67.3	33.0	381.7	64.4
50.0	119.8	58.2	406.6	100.7
70.0	177.7	85.7	430.1	133.3
100.0	274.1	130.9	463.1	176.8

Figure 1.

THEORETICAL RELATIONSHIPS

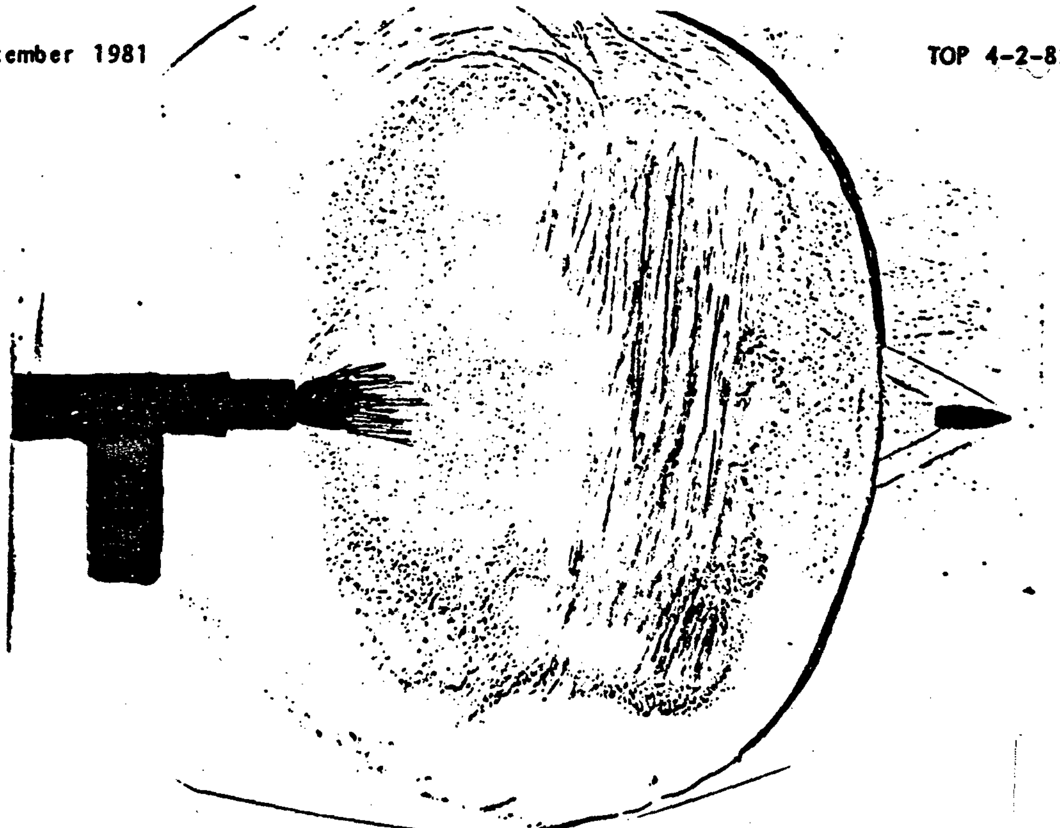


Figure 2. Photograph of muzzle blast waves and exiting projectile from an M16 rifle (photo courtesy of US Army Ballistic Research Laboratory).

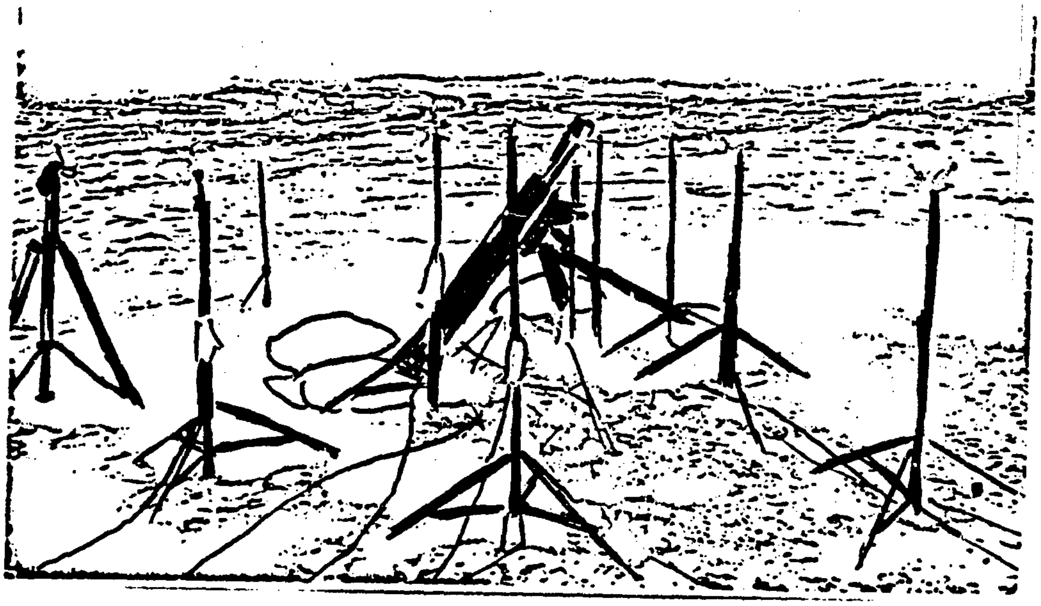


Figure 3. Transducer layout to measure muzzle blast overpressure in the crew area of an 81-mm mortar.

c. Place a control transducer at ground surface on either the 135° or 225° radial at a ground distance of 100 calibers, measured from a point directly under the muzzle, with the tube horizontal (except for mortars).

d. Align all transducers with the plane of the sensitive element passing through the axis of the weapon barrel, thereby measuring at grazing incident to the blast wave. The sensitive element will be up. The intent is to measure the side-on pressure from the primary wave and any secondary explosion (such as caused by unexpended propellant or detonatable gases outside the muzzle) that occurs along the axis of the barrel. This technique will tend to minimize the arrival of shock waves at transducer incidence angles between 0° and 90° where overshoot and ringing occur. When the weapon elevation is changed, the orientation of the transducer is changed accordingly.

The complex waveform resulting from muzzle blasts, particularly in potential crew areas, is multi-directional. However, an omni-directional side-on pressure-time measurement is impossible with existing transducers. The best that can be achieved is to predict the direction from which the highest side-on overpressure can be expected. NOTE: Extreme care should be taken in predicting the major blast wave propagation direction for each measurement and particularly for those weapons that have multiple sources of blast, such as recoilless rifles and rocket launchers.

e. Wire, fuze, and arm the test item, using specially trained personnel. NOTE: Safety switches are employed in the firing circuit.

f. Connect the firing circuit to the recording instrumentation so that the instrumentation engineer controls the moment of firing.

g. Fire at least 9 rounds, 3 each at the minimum service elevation (usually zero degrees, except for mortars), the maximum service elevation, and at an elevation mid-way between. If separate-loading ammunition or mortar ammunition is being tested, muzzle blast tests will include measurements at maximum charge. If the extreme spread of peak pressures of the 3 rounds fired at any elevation exceeds 3 dB, additional firing is required until the number of rounds fired at a given elevation exceeds the extreme spread of peak pressures in dB. NOTE: For interior measurements when the blast direction is uncertain (or arriving from many directions), orient the transducer with the sensing surface up, and with the plane of the sensing surface intersecting the center of the major suspected source, e.g., muzzle or open hatch.

h. Recalibrate transducers immediately after field use. If this post-fire calibration varies significantly (10%) from pre-fire calibration, data taken with the transducer may not be valid. If data from this transducer are presented in the report, a note must be included describing the discrepancy.

5.1.2 Data Required. Record the following:

a. Type of weapon, manufacturer, model number, and serial number of major components of the weapon system; list type of muzzle brake, if used

b. Type and lot number of projectiles and propellants

c. Weight and charge number of propellant

d. Test site ambient conditions of atmospheric pressure, temperature, wind velocity and direction at each firing time.

e. Block diagram of recording and analysis instrumentation including manufacturer and model number

f. Location, height, and orientation of each gage
g. Typical photos of test setup and typical pressure-time traces, with an exact description of how peak pressure values were obtained

5.2 Blasts from Explosives.

5.2.1 Method.

a. Support projectiles and warheads vertically, with the nose down and no less than 61 cm from the ground, subject to test requirements. The size of the projectile/warhead will dictate how it should be supported, i.e., by scaffold or wooden stand.

b. Support bare charges or mines at no less than 1.2 m above the ground on a suitable support, subject to test requirements. NOTE: In some cases, it may be necessary to place bare charges or mines on the ground or bury them.

c. Direct Pressure Instrumentation.

(1) Position blast gages no less than 1.2 m above the ground and aligned toward the item being tested (as described in Paragraph 5.1.1.d for side-on transducers and Appendix A otherwise), unless specific test requirements dictate otherwise.

(2) When testing projectiles, warheads, bare charges, and mines, place 8 to 12 blast gages in two or three concentric circles (four to a circle) around the charge at distances where overpressures of interest are expected. (When personnel or fragile materiel are of concern, overpressures of interest are usually in the .2-to-69-kPa (0.03-to-10-psi) range.) Position the gages in each circle at 90° intervals, with the second and third circles, if any, being rotated to provide equal angular separation between gages. NOTE: Approximate overpressure levels and distances may be determined in accordance with reference[6].

d. Shock Wave Velocity Instrumentation.

(1) Use two velocity gages instead of one blast gage as described above. (NOTE: Only peak pressure can be measured with these gages.)

(2) Mount the gages 60 cm apart: the first 30 cm in front of the blast gage they are replacing (toward the test charge), and the second 30 cm behind it.

(3) Separate the velocity gages by 8 cm vertically so that the front gage does not disturb the shock wave for the rear gage. (NOTE: The velocity gages should be placed either 15 cm above or below the blast gage when the blast gage is left in place.)

e. Wire, fuze, and arm the test item, using specially trained personnel.
f. Connect the firing circuit to the recording instruments.
g. Detonate the test item.

5.2.2 Data Required. Record the following:

a. Type, weight, nomenclature, and height of explosive device
b. Data as required in paragraph 5.1.2.d, e, f, and g

6. DATA REDUCTION AND PRESENTATION. The report will present pressure-time data scaled to standard conditions. Representative pressure-time traces will be included in the report, with an exact description of how peak pressure values were obtained from the data. SI units will be used with dB's and psi. A block diagram of recording data system will be given, including manufacturer, type, and model number of each system component. A detailed description, including serial number, model number, etc., of all components of the weapon system being tested, along with type and lot number of projectiles and charges, will be included. This description will be sufficiently detailed as to allow a complete reconstruction of the weapon system test.

6.1 Direct Pressure Method. From the oscillograph/chronograph readings:

a. Prepare charts of airblast overpressure versus time.
b. Determine the following:

(1) Peak overpresssure level (kPa)
(2) Positive overpressure (A duration) (usually msec), as defined in MIL-STD-1474B.
(3) Positive overpressure impulse (usually kPa-msec), if determining damage to structures
(4) B-duration, per MIL-STD-1474B, if appropriate

c. Using the "worst case" test results for a particular test condition, determine the number of rounds that can be fired using single and double ear protection, as specified in MIL-STD-1474B. If any firing exceeds limit 2 in Figure 5 of MIL-STD-1474B, the weapon is considered to have exceeded the limits specified in TB MED 501, and approval of such a weapon must be obtained from the surgeon general (DASG-PSP). For a given test sample, the worst case is defined as the firing that produced the greatest value when the peak pressure is raised to the 3.0103 power, multiplied by B duration.

6.2 Shock Wave Velocity Method. The relationship between shock front velocity and side-on overpressure, known as the Rankine-Hugoniot equation, provides the basis for deducing overpressure from wave front velocity. Compute shock wave velocity and overpressure as shown in Appendix F.

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APPENDIX A

OVERPRESSURE-MEASURING DEVICES

For an ideal gage, the measuring orifice should be at such a position on the gage that the velocity in that area is equal to the stream velocity remote from the gage. The gage shape should be chosen so that its accuracy does not depend too greatly on change of gage orientation with respect to the main stream. The gage, when inserted into the pressure wave, should present minimum obstruction to the wave, and have an aerodynamically streamlined form.

The most commonly used gage for direct pressure measurement of airblast employs piezoelectric crystals as the sensing element. The crystal element generates an electrical charge that is proportional to the amount of compression applied to the crystals by the dynamic air pressure.

Blast pressure gages may be constructed in several forms (Figure A-1). The following types are currently used:

a. Pencil gage (LC-33). This gage measures side-on overpressure, and is shaped like a pencil. The ring-shaped sensing element of lead zirconate is mounted flush with the outer surface of the body for proper air flow across the element. In use, the gage is pointed toward the detonation. The high acceleration sensitivity, long rise time, and low resonant frequency of this transducer make it unacceptable by the standards presented in reference 5 for measurements made to determine human tolerance to blast overpressure. This transducer is still used to measure blast from land mines, exploding projectiles, and other explosives.

b. Pancake/lollipop gage. This gage also measures side-on overpressure, is shaped like a pancake, and uses a sensing element mounted in a circularly shaped housing. During use, the gage is positioned vertically "edge on" to the blast wave.

c. Miniature gages (ST-2 and PCB-113). Small gages about 1 cm in diameter, with sensing elements (crystals such as tourmaline, quartz, lead zirconate, titanate lead metaniobate, etc.), 0.5 cm or smaller are available for a variety of measurements (side-on, face-on, or stagnation), depending on how the gage is mounted. Because the sensing element is small, a blast wave travels over it quickly, and a short rise time is observed. This characteristic is important in measuring blasts from small arms because the pressure decays rapidly after wave passage. The voltage output-type device, containing an integral source follower amplifier, is most common, although charge-type and strain-type outputs are also available.

Miniature gages can be placed in several mounts, e.g., pencil probe, best suited for applications when the exact shape of the wave form is critical and the blast source is well defined and presents an easy point for alignment; skimmer plate, best suited for applications when exact shape of the wave form is still critical, and an omni-directional plane is needed (such as near a gun muzzle); and the blunt cylinder mount which is best suited for measuring in complicated blast fields where small errors in wave shape are preferable to large errors due to unavoidable misalignment. This last mount is ideal for low pressure fields. For a detailed description and comparison of these mounts, refer to <u>Improvement of Airblast Measurement</u> (APG-MT-5481).[7]

d. Strain-type gage. The Endevco 8510 (see Figure A-1) is a newly developed piezoresistive strain-type transducer. This gage has DC response and is temperature-compensated to minimize response to thermal transients and scale factor change due to temperature change. Because of its DC response, it is the easiest gage to calibrate, and shows excellent agreement between static pulse calibration method and sine wave method. However, the diffused silicone diaphragm used on the Endevco gage acts not only as a pressure sensor, but also (unfortunately) as a light sensor. A flash bulb set off in front of an Endevco gage will cause a full-scale indication. The photosensitivity of this gage could be a problem in measurement locations near muzzle flash or the fireball of free air explosions. Furthermore, ringing and wave distortion of the Endevco gage are significant problems. For this reason, the gage was used mainly for assistance and verification of calibration techniques.

e. Velocity gage (LC-70). This gage was used in pairs to measure velocity of shock wave (convertible to side-on overpressure by the formula in Appendix F), or singly to measure arrival time of shock wave. Although used widely for calibration of other gages, it has limited use for test purposes because the gages in pairs produce only peak overpressures, rather than overpressure-versus-time trace.

Selection of a transducer for critical blast overpressure tests should be based on thorough testing of the transducer's characteristics under known conditions. Particular attention should be given to the following characteristics:

(1) Blast wave response (overshoot, ringing, flow effects)
(2) Acceleration sensitivity
(3) Temperature sensitivity
(4) Ease and repeatability of calibration

Transducer Specifications. The transducers to be used for obtaining pressure-time data from the muzzle blast of a weapon shall meet these requirements:

a. The resonance natural frequency shall be 75 kHz or greater

b. If the transducer does not have DC response, the time constant will be at least 200 ms.

c. The non-linearity will be 3% or less of the full-scale output of the transducer.

d. The transducer shall be chosen to minimize the effects of temperature at the expected temperature range to be used. Output will be corrected from temperature versus sensitivity curves for the individual transducer.

e. The sensitive element shall have a diameter of 6 mm or less. Transducer holders or housings should be of minimal size to mount securely and to incorporate good aerodynamic design so as to minimize interference to the flow over the sensor surface.

f. The acceleration sensitivity will be no greater than 0.014 kPa/g (0.002 psi/g) in the axial direction, and no greater than 0.069 kPa/g (0.01 psi/g) in the transverse direction.

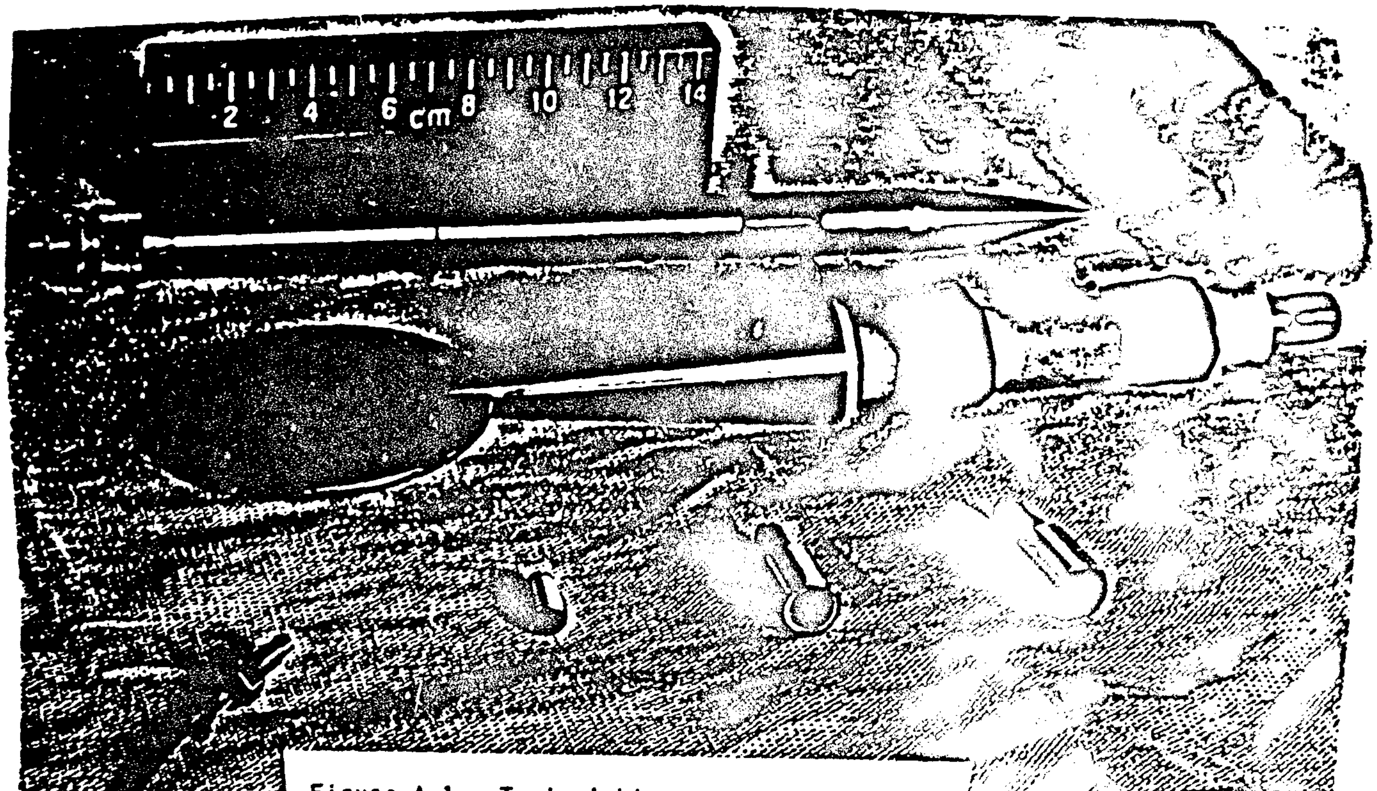

Figure A-1. Typical blast pressure gages.